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DEVELOPMENT OF A META-ANALYTIC TECHNIQUE TO ASSESS STRESS EFFECTS

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The true test of military systems and personnel is their ability to operate efficiently in the high stress combat environment. This is especially true in the field of combat maintenance, because the maintenance function is essential to maintaining the high rate of sorties required on the future battlefield. Yet maintenance personnel, although highly trained and skilled technicians, receive little preparation for the extreme stresses of the combat environment. The present effort takes a unique and innovative approach, utilizing a meta-analytic technique, to identify the stress factors that restrict or limit effective performance. Preliminary analyses examining the effects of time pressure, group pressure, and noise on performance indicate that this approach is technically sound and of significant practical value.

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SUMMARY

Research conducted from World War II to the present indicates that the stress of combat is a primary source of task and mission performance decrement. It is the true test of military systems and personnel that they operate effectively in this high stress environment. This is especially true in the field of combat maintenance, because the maintenance function is essential to sustaining the high rate of sorties required on the future battlefield. Yet maintenance personnel, although highly trained and skilled technicians, receive little preparation for the extreme stresses of the combat environment.

This paper documents the results of a Phase I Small Business Innovation Research (SBIR) project to examine the impact of stress on the combat maintenance environment. This project takes a unique and innovative approach, utilizing a meta-analytic technique, to identify the stress factors in the combat environment that restrict or limit effective performance. The objective of the Phase I research was to establish the feasibility of this approach. A preliminary analysis was conducted examining the effects of time pressure, group pressure, and noise on performance. Results indicate that this approach is technically sound and generates data that are of significant practical value.

PREFACE

The work reported in this technical paper was performed by Eagle Technology, Incorporated as a Phase I Small Business Innovation Research (SBIR) project. This work was accomplished under ASD contract F33615-88-C-0017 for the Air Force Human Resources Laboratory (AFHRL). Ms. Cheryl L. Batchelor monitored this contract for the Laboratory.

This contract is one of several parts of a more global effort being examined by the AFHRL Combat Logistics Branch. The impact of combat stress on aircraft maintenance personnel is a program which is looking at the feasibility of developing stress reduction methodologies. If the various methodologies proposed are proved to be feasible, follow-on efforts will look at the actual development of specific stress reduction programs. This Phase I effort has shown the feasibility of using a meta-analytic approach to assess stress effects.

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I. INTRODUCTION

The intensity of combat in World War II resulted in over 50 psychiatric casualties per division per day. What would happen if the intensity were stepped up by around-the-clock operations, more sophisticated weapon systems, and an enemy vastly superior in numbers? U.S. combat forces are likely to face such a scenario in the future battlefield. According to the Soviet view, the successful execution of a conventional war requires tactical surprise, a high-speed offensive operation, and deep penetration of the forward line of battle. Defensive forces are likely to find themselves overwhelmed and fighting to the front and rear from the very outset of the conflict. How would this impact the stress casualty rate?

A partial answer can be provided by the 1967 and 1973 Arab/Israeli conflicts. In 1967, when Egypt defended against a surprise attack by a superior Israeli force, Egyptian stress casualties outnumbered those wounded in action by almost 3 to 1. In 1973, when this scenario was reversed, an estimated 900 out of the first 1,600 Israeli casualties had no physical injury (Labuc, 1984). U.S. experts predict that in a conventional war, the combat stress casualty rate will be approximately 25% of total casualties. In a nuclear or chemical war, this rate may increase to 50% or higher.

Several points should be emphasized in regard to these estimates. First, they are based on past conflicts. The impact of stress on mission performance in the high-intensity, high-technology battlefield of the future is likely to be much higher. Second, these estimates simply reflect stress casualties, those who are debilitated by the combat environment. The majority of personnel never become stress casualties, but nevertheless may experience moderate to severe task degradation stemming from the stress environment. The increased errors and poor performance that result may jeopardize mission effectiveness to a greater extent than does the actual stress casualty rate. Third, these estimates are derived largely from observations of infantry troops. The effects of stress in degrading the performance of complex tasks such as those routinely performed by combat maintenance personnel are likely to be even greater. Finally, as Batchelor (1988) noted in addressing the Air Force maintenance environment: if we expect trained combat troops to sustain this degree of loss from stress, then should we not expect much greater losses in the combat environment from maintenance personnel, who view themselves more as technicians than hardened combatants? The result is that combat stress, reflected in stress casualty rates and in degraded task performance, will be a significant determinant of mission effectiveness in the future battlefield.

Brigadier General S. L. A. Marshall, the noted World War II historian, provided this view of war:

> [War] determines who is the best man--who is the highest-bred, the most self-denying, the most fearless, the coolest of nerve, the swiftest of eye and hand. You cannot test these possibilities wholly, unless there is a clear possibility of the struggle's ending in death. (Marshall, 1947, p. 157)

Marshall emphasizes the critical point that war is the proving ground of military preparedness. It alone determines whether our investments in time, material, and training of military personnel have been successful. Those who are best prepared will survive. However, Marshall errs on the second point that he implies--that you cannot prepare for this environment outside of the battlefield. In fact, exposure to realistic combat conditions is necessary to prepare personnel to maintain effective performance in combat. However, the concern of military and civilian researchers is invariably that "we don't know how to effectively measure (or manipulate) stress."

The search for a reliable and realistic setting in which to examine stress effects has led military researchers undersea (Radloff & Helmreich, 1968), aboard airplanes (Berkun, Blalek, Kern, & Yagi, 1962), into firetowers (Berkun et al., 1962), to parachute school (Burke, 1980), and into combat (Williams, 1984). Training exercises that are available to simulate a stress environment, such as the "gas chamber" drill used for chemical defense training by all services, are based primarily on perceptions of physical fidelity to the stressor environment. For example, the gas chamber procedure for chemical defense simulation is based on a procedure designed in World War I for the purpose of building performance confidence in this environment. However, research data suggest that the training effectiveness of such a procedure may be woefully inadequate (Driskell, 1984, 1986). Other stress simulations developed for training and/or research purposes are usually based on intuitive guidelines of what constitutes a realistic stress environment, and are also likely to be of questionable effectiveness.

This technical paper documents the results of a Small Business Innovation Research (SBIR) project to examine stress and combat maintenance performance. This project takes a unique and innovative approach, using a meta-analytic statistical technique to isolate the effects of stress factors in the combat environment that limit or degrade effective performance.

SBIR projects are funded and performed in a three-phase process. Phase I demonstrates the project's scientific and technical merit and establishes the feasibility of the proposed

approach. The purpose of Phase I is to test the project's methodology, to demonstrate that the technical approach proposed is feasible. The present paper describes the results of the Phase I effort of the current project. The most successful Phase I projects become eligible for Phase II, in which the proposed research is carried out. Phase III consists of follow-on funding for further application of the research.

The overall goal of this project is to enhance maintenance performance in the combat environment. The technical objectives of this work are:

1. to identify what psychological stressors (threat, uncontrollability, time pressure, noise, etc.) must be present to effectively simulate combat stress in a reliable manner;

2. to identify the extent to which each stressor affects performance speed, accuracy, psychological reactions, and physiological reactions;

3. to identify the most effective way to manipulate each stressor;

4. to identify factors (such as team cohesion, leadership, etc.) that moderate stress effects; and

5. to develop a precise set of functional specifications for simulating the stress environment.

The technical questions that this project addresses include the following:

- What are the factors that determine a reliable and effective stress environment?

- How do we effectively simulate the stress environment for training and/or research purposes?

- What are the factors that must be present to achieve psychological fidelity in a stress simulation?

- How should they be presented or manipulated for maximum effect?

- What factors have been shown to moderate the effects of stress on task performance?

The remainder of this paper describes the technical problem addressed by this project, the approach taken to solve the problem, and the results of the Phase I research conducted to establish the feasibility and scientific merit of this approach.

Background

Few individuals become accustomed to emergency, hazardous, or extreme stress conditions, simply because such situations are rare. For example, military personnel rarely, if ever, experience an intense combat surge. Nuclear power plant workers are seldom faced with the extreme stress conditions of a nuclear incident. Yet, we know the potential for serious error that these types of situations engender; e.g., risky decisions are made, skilled performance declines, and crucial information is ignored (see Foushee, 1984). In these situations, where performance is crucial, military personnel must be prepared to perform under hostile, extreme stress conditions. The effects of stress on task performance, and the mitigation of these effects, are areas of critical concern to the military.

The problem of maintaining effective task and mission performance under stress has been consistently identified as a priority area for military research (see Driskell & Olmstead, 1989). The topic of stress was identified as a priority focus for military research as early as 1917 (Yerkes, 1918); and as recently as 1988, a chapter in the National Research Council report Enhancing Human Performance was devoted to the management of stress (Druckman & Swets, 1988). Regardless of the extent of technological advancements made to enhance the performance of military personnel, the problem of maintaining effective task performance in a stressor environment will remain.

In fact, the complexity of modern military systems and the intensity of the high-technology battlefield may cause combat stress to become an even more significant factor in mission performance. Today's sophisticated military systems are evidence that the person-machine system is the fundamental military unit. Even with advances in system capabilities, the individual plays an increasingly critical role in the operation and maintenance of military systems. The impact of stress on the combat maintenance environment may operate to negate technological advances that have been achieved in combat systems, because the overall system performance is jeopardized when the human component is degraded.

The concern with effects of stress on task performance is of central interest to the military for several reasons. First, the military operational environment is, by definition, a high stress environment. Both personnel and equipment must be prepared to operate efficiently in this combat environment, which is the true test of military preparedness.

Second, the effects of stress on performance are profuse and well documented. Research has identified numerous effects

of stress, including: physiological arousal such as increased heartbeat, labored breathing, and trembling (Rachman, 1982); motivational losses (Innes & Allnutt, 1967); increased self-monitoring (Carver, Blaney, & Scheier, 1979); stressor aftereffects (Cohen, 1980); cue restriction and narrowing of the perceptive field (Combs & Taylor, 1952; Easterbrook, 1959); decreased search behavior (Streufert & Streufert, 1981); longer reaction time to peripheral cues and decreased vigilance (Wachtel, 1968); degraded problem-solving (Yamamoto, 1984); performance rigidity (Staw, Sandelands, & Dutton, 1981); and even lowered immunity to disease (Jemmott & Locke, 1984). Data show that performance stress alone may increase errors on operational procedures threefold (Villoldo & Tarno, 198[illegible]). Similarly, Idzikowski and Baddeley (1983) found that the time taken to complete manual tasks doubled under stress conditions.

The magnitude of this problem has been recognized for some time, particularly in the area of combat performance (Marshall, 1947; Schwartz & Winograd, 1954). For example, stress effects during the Normandy campaign in World War II were such that,

> ...the [combat] soldier was slow-witted; he was slow to comprehend orders, directions, and techniques. Memory defects became so extreme that he could not be counted upon to relay a verbal order. (Siegel et al., 1981, p. 13)

A final reason for the historical emphasis of the military on stress research is that failure to consider and prepare for the effects of stress on soldier performance exacts such a high price. That is, stress-induced decrements in performance are most likely to occur when they can be least tolerated: during critical combat situations. It has been noted that performance in a high stress environment will degrade even the best-trained unit; however, it will eliminate the untrained unit.

Yet, historically, the military has conducted little research to examine stress in the <u>combat maintenance environment</u>. With the notable exception of a program of research addressing aircraft maintenance units (see Batchelor, 1988; Kane, 1986), one would have to assume by the amount of research devoted to this area that maintenance personnel are less vulnerable to stress effects than aircrews or infantry. Several reasons suggest why this assumption may be a critical mistake:

1. Maintenance tasks that involve complex cognitive skills are more vulnerable to degradation from stress than more labor-intensive tasks. For example, French (1983), examining the performance of military personnel using speech recognition systems, found that recognition rates declined when the

operators were placed under stress. Villoldo and Tarno (1984) found that procedural errors made by explosive ordnance disposal personnel increased by a magnitude of three when the operators were under stress.

2. The Air Force relies on effective maintenance to generate sorties and maintain mission performance. There are several trends in the combat maintenance environment that are likely to increase the potential for significant combat stress effects, including (a) continued increases in system complexity; (b) the requirement to sustain intense combat surges of up to 72 hours, with corresponding high sortie rates; and (c) dispersed basing and mobile teams. Yet, maintenance is often treated as a "given" when the future battlefield is considered.

3. In past conflicts, maintenance tasks were performed in the rear of the forward line of battle. In the future battlefield, there will be no identifiable rear, and maintenance personnel will perform under the most extreme conditions imaginable. However, maintenance personnel have no tradition of performance in the face of combat, no role models, no weapons, and little preparation for this environment.

4. Finally, maintenance personnel do not train for combat. Army infantry have the Multiple Integrated Laser Engagement System (MILES), which allows them to exercise under simulated combat conditions. Pilots have sophisticated simulators and emergency training programs such as Situational Emergency Training (SET), which allow them to practice under stress conditions. Maintenance personnel train for peacetime conditions, rather than for wartime. Even the Instructional Systems Development (ISD) approach that is used to develop military training is couched in non-combat terms. For example, a training standard might read "Given an oscilloscope, the trainee will be able to troubleshoot..." More realistically, the standard should read "Given an oscilloscope, threat conditions, time pressure, fatigue, the trainee will be able to troubleshoot..." As summarized by the military panel investigating the USS Vincennes incident, training most often occurs in a "calm and rehearsed environment" which is quite unlike what will be faced under operational conditions.

In summary, combat stress has been recognized as a critical area of military research for some time, as evidenced by research carried out by American researchers (Burke, 1980; Driskell, Moskal, & Carson, 1987) as well as Israeli (Friedland & Keinan, 1986), British (Labuc, 1984), and Soviet (Solov'yeva, 1981) researchers. In summarizing this threat, a recent report from the U.S. Army School of Advanced Military Studies concluded: "Combat stress will be one of the most significant causes of loss of manpower" (Coomler, 1985, p. 34). This

opinion is supported by Navy researchers who claim, "During critical periods of a mission, susceptibility to (psychological) threat may be the decisive factor between success or failure" (Wherry & Curran, 1966, p. 228).

Problem

Research and observation confirm that combat stress plays a major role in the operational military environment. Therefore, in order to maintain performance in this environment, should not stress factors be critical elements in the design of simulation and training for combat maintenance personnel?

The problem faced by the military is to maintain effective task and mission performance under high stress combat conditions. One crucial component in maintaining personnel performance in a stress environment is to provide practice and the exercise of critical tasks under operational conditions similar to those likely to be encountered in the real environment. Training that allows the simulation of novel or high stress environmental conditions has been successful in a variety of military applications, including water survival, escape training, and firefighting. Thus, "realistic" training and simulation is seen as one critical instructional strategy to prepare personnel to operate in the stress environment.

However, there is little available information on how to create these training conditions. That is, there is little empirical guidance available on how to simulate effectively a stress environment for training purposes, or how to design training systems for specific stressor environments. The conclusion from a recent National Research Council report on the topic states:

> Although the stress effects occurring in real environments are purported by military and civilian managers to be an important factor in realistic training...there exists a lack of understanding of stress that occurs or can be induced in simulations. Very little research has addressed problems in this area. (Jones, Hennessy, & Deutsch, 1985, p. 63)

Other researchers have also noted that no adequate database on human performance under stress is available to guide applied efforts. Wickens and Rouse (1985) conclude:

> When a system designer wants to know how far 45% of the pilot population can reach, before a control's location is established in the cockpit, the figure is available from a data base on human anthropometry. But when the designer wants to

> know...how the operator's mental model of a computer-based automated system is affected by fatigue, only the fuzziest of answers may at present be provided. (Wickens & Rouse, 1985, p. 6)

State-of-the-art simulation and training techniques can reproduce a specific operational environment with extraordinary physical fidelity. A maintenance trainer or a training mockup can be developed with exact spatial, aural, and visual specifications for training. Yet, when we attempt to develop a "stress training overlay" for that system, or try to develop the functional specifications for a "stressor environment" for training and/or research purposes, guidance on how to accomplish this is at best ad hoc and intuitive rather than systematic and theory-based. That is, we can effectively design the physical fidelity of a training system, but reaching the goal of psychological fidelity in simulating a stress environment is a more difficult task.

In most cases, the military researcher or training developer is forced to design a stress scenario or stress environment in terms of individual reactions to it in an ex post facto manner (i.e., they design a stress environment on intuitive grounds and then assess individuals' reactions), or the researcher or designer simply projects what he or she thinks would be stressful (i.e., they define a situation as stressful because they assume it would be stressful to them). In most cases, they end up with a situation or training scenario with physical fidelity and face validity (i.e., it "looks" like a stress environment), but little psychological fidelity (i.e., it does a poor job of manipulating stress).

The result is that the military researcher has few specific procedures and few specific tools to provide maintenance personnel that will help overcome stress degradation and sustain task performance in the critical combat environment.

II. TECHNICAL APPROACH

In the combat environment, military personnel encounter one of the few settings universally acknowledged to entail extreme stress. Military combat is the proving ground of military preparedness. The goal of military manpower and equipment preparedness is to win the next war. Thus, the "bottom line" of military preparedness is how well individuals perform under the stress of combat conditions.

Laboratory research has found that, for some tasks, normal training procedures (practice conducted under normal non-stress conditions) do not improve task quality when the task has to be performed under stress conditions (Zakay & Wooler, 1984). These

results suggest that, under certain conditions, transfer of training from classroom conditions to conditions on the battlefield may be poor, without stress-inclusive simulations or training. Thus, one component of effective training systems is to prepare individuals to perform critical mission tasks under the high stress operational conditions with which they will be faced. Combat simulations or training exercises that allow personnel pre-exposure to the stress operational environment should reduce the extent of performance decrement encountered in the actual combat setting. This strategy has been successful in a number of military applications, including water survival, flight emergency training, and firefighting.

In most cases, a training situation is designed with a certain degree of physical and psychological fidelity to facilitate the transfer of training to the actual task setting. However, these settings vary in effectiveness. Training situations such as a firefighting simulation, for example, may provide a very effective and realistic exposure to the stress performance environment it was designed to simulate, although indications are that the chemical defense "gas chamber" drill used by all the services does a poorer job. What are the factors that allow one scenario to be an effective training system, while the other fails? How does one setting effectively simulate the stress environment, while the other does not?

Figure 1 presents a model of the effects of stress on task performance. There are a number of factors which have been identified in the research literature that constitute stress stimuli. These stress factors include perceived threat, noise, perceptions of uncontrollability, time pressure, fatigue, heat stress, and other factors identified in column 1 of Figure 1. These stress factors produce a number of measurable effects, including arousal, increased heartbeat, increased errors, decreased speed of performance, decreased performance confidence, and so forth. We have organized these effects into the four categories in column 3 of Figure 1: performance speed, performance accuracy, physiological effects, and psychological effects. Finally, the effects of these stressors on performance are moderated by a number of individual and social factors identified in column 2 of this figure. For example, the effect of threat on performance may be determined by team cohesion, type and amount of training, skill level, and expectations of performance competence.

This project takes a unique approach using a meta-analytic statistical technique to (a) identify those stress factors which are critical for effectively simulating the combat stress environment, (b) identify specific effects of these stressors on task performance, psychological reactions, and physiological reactions, (c) identify moderators of these stress effects, and

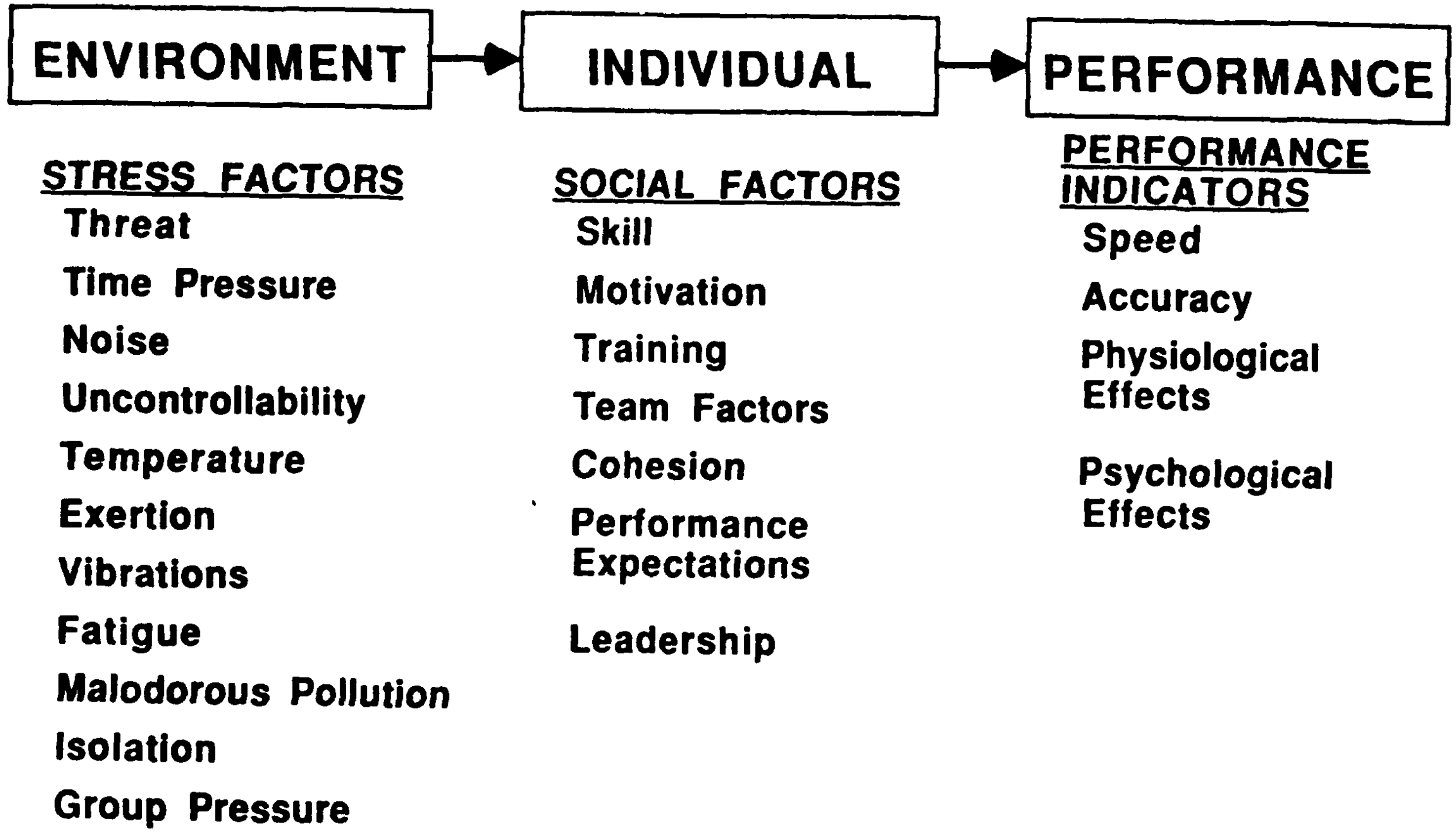

Figure 1. Model of Stress and Performance.

(d) specify how to manipulate relevant stressors to achieve an effective combat stress simulation. Rather than simply conducting yet another study to examine how, for example, time pressure impacts performance, we attempt to integrate or make sense of the large body of research on stress and performance that has been conducted by the Army, Navy, Air Force, and civilian institutions over the past several decades. We intend to take the vast amount of studies that have been funded by the military and performed in military and civilian institutions, analyze them from a comprehensive perspective, integrate the results, and summarize what they have to tell us about the effects of specific stressors on performance. The results of this meta-analytic integration of the stress literature should provide very reliable guidelines for manipulating stress.

The long-term goal of this project is to specify the relationship between each stressor (such as threat) and each performance indicator; for example, the relationship between threat and performance accuracy, threat and performance speed, threat and specific physiological measures, and threat and psychological effects. We intend to analyze the results of research in each topic area, and develop summary statistics of strength and significance of effect for that particular stressor. Perhaps more important, we will examine variables in the literature that moderate each stress-outcome relationship. For example, it may be that certain factors, such as how the stressor is manipulated, the range of manipulation, the mode of delivery, etc. <u>increase</u> the strength of the stress effect. It is important to identify such specific factors in order to develop a strong and effective simulation of the combat environment. On the other hand, it may be that certain other factors, such as type of task, leadership, or training <u>lessen</u> the effects of that stressor on performance. In order to enhance performance in the stress environment, this information is also crucial. The following description outlines the meta-analytic procedure to be used to provide these data.

It is informative to provide a distinction between <u>primary analysis</u>, <u>secondary analysis</u>, and <u>meta-analysis</u>. Primary analysis refers to the original statistical analysis of data; for example, the analysis of data collected by a researcher examining the effects of noise level on performance errors. Secondary analysis refers to analysis of data by someone other than the original investigator. For example, investigator B may re-analyze investigator A's data on noise and performance, to examine a particular variable of interest. Meta-analysis refers to the analysis of the results of several independent studies. For example, if investigators A through Z have conducted 30 studies of the effects of noise on performance errors, a meta-analysis would provide a numerical summary and integration of the results of these separate studies.

Procedures for combining and comparing the results of independent studies have been around for quite some time (e.g., Fisher, 1932, 1938; Mosteller & Bush, 1954; Pearson, 1933; Rosenthal, 1961; Snedecor, 1946; Thorndike, 1933). It was not until Gene Glass's (1976) labeling of this perspective as "meta-analysis" that this approach received the popularity and the currency that it enjoys today. Meta-analysis generally refers to the statistical integration of the results of independent studies. The term "meta-analysis" does not describe a single statistical procedure which distills a domain of research into one simple answer. Rather, meta-analysis embodies a constellation of different statistical techniques, developed and suited for specific purposes, and a general conceptual approach to the problem of summarizing, integrating and testing of practical questions and theoretical issues with the results of previous research.[1]

Procedurally, there are several distinct steps in the development of a responsible and informative meta-analytic integration. First, the hypothesis test to be examined must be carefully and precisely defined. The specific operationalizations of the independent variable and the dependent variable must be clearly articulated. For example, in the present concern with the effects of stress upon performance, the specific operationalizations of stress to be examined within a particular integration must be made explicit.

There are literally hundreds of studies (a considerable proportion of which have been funded or performed by various branches of the Armed Forces) which have examined the effects of some component of stress on some performance indicator. As represented in Figure 1, there are a number of distinct, broad classes or components of stress: time pressure, malodorous pollutants, noise, temperature, humidity, air pressure, aerobic exertion, low-frequency vibration, fatigue, diurnal flattening, and so on. In addition, there are nearly as many different performance indicators: performance speed, performance accuracy, self-reported affective response, and a plethora of physiological responses. Attempts to integrate the effects of noise on self-reported tension from one study with the effects of time pressure on performance accuracy from another study would be impractical: These different components of stress are likely to exert different effects on different performance indicators, and to be moderated by different constellations of

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[1]Terms unique to the meta-analytic approach, including statistics used in the meta-analysis, are defined in the Appendix.

intervening variables. Moreover, the practical value to be derived from such a heavy-handed integration of the effects of "stress," broadly defined, would be problematic; such an ill-defined type of integration might present some general picture of the effects of stressors, but with little or no specification of how different components of stress differentially contribute to different performance indicators. The overall goal of the present research is to provide clear, illuminating gauges of the strength and direction of each separate link represented in Figure 1.

Rather than trying to examine the effects of "stress" broadly defined, we intend to examine in turn the specific subcomponents of stress delineated in Figure 1, such as noise, time pressure, and so on. In a similar manner, the specific operationalizations of "performance" to be examined within each integration must be made explicit. Rather than trying to examine the effects of stress on performance broadly defined, we will examine in turn the specific subcomponents of performance delineated in Figure 1, such as speed and accuracy.

After a well-defined hypothesis test has been identified, the relevant studies must be located and retrieved. Relevant studies may be located in published academic journals, scholarly textbooks, unpublished papers presented at conferences, unpublished theses and dissertations, and published and unpublished technical reports. Several distinct strategies are employed to locate relevant studies. The Ancestry approach uses the bibliographies and reference sections of relevant studies which have already been retrieved to locate earlier relevant studies. The Descendency approach uses indexing sources (such as Social Sciences Citation Index) to retrieve subsequent relevant studies which have cited earlier relevant studies. Abstracting Services (such as Psychological Abstracts, Defense Technical Information Center, and Educational Resources Information Center) allow the user to identify studies associated with key words and phrases. All three of these approaches (Ancestry, Descendency, and Abstracting Services) can be conducted via on-line computer databases. The "Invisible College" approach refers to the informal network of scientists working on a given problem. Letters, phone calls, and conversations with researchers most active in a particular research domain can sometimes uncover new, unpublished studies at various stages of being "in the works." Our research will be able to build on the database of over 1,300 studies of stress and performance that were identified in Phase I using the above approaches.

Once the relevant studies have been retrieved, the appropriate tests of the specific hypothesis to be examined must be derived from the study report. Sometimes this is perfectly

straightforward. Very often, however, researchers will report imprecise or imperfect tests of the relevant hypothesis. For example, researchers will sometimes identify the difference between two means as being simply "significantly different," without reporting a statistical test of the difference. Similarly, researchers will sometimes report an overall $\underline{F}$-test (based on more than 1 degree of freedom in the numerator), indicating that some treatment means differ, without indicating which means differ. In these instances, we must reconstruct the original analyses from reported means, standard deviations, and other related but different $\underline{F}$-tests.

Of course, one study may report a $\underline{t}$-test, a second study may report a chi-square, a third study may report a correlation coefficient, and so on. Because these statistics are on different metrics, they must be transduced to more standard, common metrics. The two common metrics for statistical results are significance levels ($\underline{Z}$ and one-tailed $\underline{p}$) and effect size (Fisher's $\underline{Z}$, $\underline{r}$, $\underline{r}^2$, and $\underline{d}$). Once placed on common metrics, the significance levels and effect sizes of separate hypothesis tests can be combined, compared, and examined for the fit of predictive models. Basic meta-analytic combinations of significance levels and effects sizes provide a gauge of the overall combined probability and strength of the effect of that component of stress on that performance indicator. Meta-analytic focused comparisons provide a gauge of the extent to which that effect of stress on performance increases or decreases as a function of some theoretically relevant or practically important moderator (formulae and computational procedures for these meta-analytic techniques are presented in Mullen, 1989; Mullen & Rosenthal, 1985; Rosenthal, 1984).

This strategy presents the opportunity to do two very useful things. First, it can provide a very specific and precise summary of the overall effects within a given research domain. For example, by analyzing each study that has examined the effects of noise on performance speed, we can provide summary statistics indicating the magnitude and significance of this effect. Second, this strategy allows us to test specific models and theoretical assumptions which would be exorbitantly expensive, or practically impossible, to examine at a primary level of analysis. For example, we are able to examine the effects of factors that may moderate the effects of noise on performance speed, such as the mode of presentation or the effects of continuous noise versus noise bursts. This can provide valuable practical information on how to effectively manipulate these variables. For overviews of the meta-analytic approach, see Cooper (1984), Mullen (1986, 1989), Mullen and Rosenthal (1985), and Rosenthal (1984).

Over the course of this project (Phase I and Phase II), we intend to examine each of the following stressors, prioritized as follows in terms of their likely criticality to the combat maintenance environment:

1. Threat. Almost all definitions of stress include the concept of threat: the fact that stressors threaten the individual's physical or psychological well-being. This threat is paramount in the military combat environment. In fact, military researchers in World War II concluded that the central fact of combat was danger to life and limb (Williams, 1984). The capability to effectively simulate the danger and threat of this environment is critical.

2. Uncontrollability. Whether or not the individual can manipulate or control the environment is a significant determinant of stress. For example, researchers have found that individuals in an overcrowded elevator experience a much less negative reaction if they are able to stand next to the control panel than if they do not have this perceived ability to control their environment. This phenomenon is particularly important to the combat maintenance environment because maintenance personnel must perform a task under very hostile conditions and yet are not issued weapons to respond to attack. It is likely that this inability to manipulate or respond to the external stressor environment is a significant factor in combat maintenance performance.

3. Fatigue. In combat, maintenance personnel will be forced to respond to intense combat surges of up to 72 hours while maintaining high sortie rates. Of special concern are physical fatigue resulting from deprivation of rest, perceptual fatigue caused by habituation or adaptation effects, and skill fatigue caused by repeated performance over time.

4. Time Pressure. Time pressure has a severe effect on decisionmaking and accuracy of performance. Research has shown that under time pressure, task performers make poorer decisions and more errors. It has been suggested that under time pressure, individuals tend to conserve on cognitive activity, preferring simple task strategies over more complicated procedures--a proposition that has significant implications for the performance of complex tasks.

5. Group Pressure. Individuals may train alone, but they often work together, or at least interact with and work among various others on the battlefield. Research has shown significant effects of working alone versus working among or in the presence of others who serve as potential distractors.

6. Noise. The effects of noise, both continuous and variable, on task performance are broad, ranging from increased accidents to impaired judgement. Noise may result in impaired attention, increased operator errors, impaired recall, poor communication, and fatigue.

7. Climatic conditions. Although heat and cold affect performance differentially, both can greatly impair skilled behavior. There are several factors that combine to determine the human thermal state and the subsequent ability to perform, including length of exposure and skill and motivation levels.

8. Isolation. In World War II, Marshall (1947) wrote, "The battlefield is cold. It is the lonesomest place which men may share together" (p. 44). Although an individual may be in the midst of many others, with dispersed bases and mobile teams there is still the perception of isolation from the larger unit. Individual isolation is expected to be a particular problem in the event of chemical warfare, when protective gear is worn and one person is perceptually and physically unidentifiable from another.

9. Diurnal Flattening. The disruption of circadian rhythms and work efficiency resulting from continuous operations is a significant factor in combat performance.

10. Malodorous Pollution. The fumes and smell of the combat battlefield may serve as a distractor in a manner similar to that of visual and auditory stressors.

Equally as critical as prioritizing those characteristics that serve as environmental stressors is the importance of setting a priority for examining those characteristics that may moderate the effects of stress on performance. One advantage of the meta-analytic approach is the capability to integrate and summarize volumes of material, and discover patterns of relationships that are not evident when looking at the individual studies. A limitation of the meta-analytic level of analysis is that, in one sense, it cannot generate new data. In other words, if none of the studies in the domain of noise stress have ever examined training as a moderator, then this variable would not be available for analysis.

Factors that may serve as important moderators of the stress-performance relationship include the following:

1. Type of Task.

2. Leadership.

3. Team Cohesion.

4. Type and Amount of Past Training.

5. Attitudes or Performance Expectations.

6. Individual Skill Level.

Phase I Objectives

The objective of Phase I was to establish the feasibility of this approach. The Phase I research was conducted to demonstrate the success of the procedure and the value of this approach in providing answers to the problem addressed. We believe that the Phase I results clearly demonstrate that the Phase I objective has been achieved.

The Phase I research examined three stressors that have been the subject of considerable research in the stress and performance literature: (a) time pressure, (b) group pressure, and (c) noise. Consistent with the meta-analytic approach, the first step taken was to develop specific hypotheses to be tested. In this case, we separately examined the effects of time pressure, group pressure, and noise on each of four performance indicators (performance accuracy, performance speed, physiological effects, and psychological effects). Next, we located and retrieved studies that have tested these relationships. We developed a database of over 1,300 studies on stress and performance drawn from the Defense Technical Information Center (DTIC), National Technical Information Service (NTIS), and PSYCHINFO databases. We then analyzed the results from each study that dealt with time pressure and performance accuracy, time pressure and performance speed, and so on for each of the three variables tested in Phase I. Therefore, for each relationship (for example, the relationship between time pressure and speed of performance), there might be 5 to 50 hypothesis tests (i.e., there might be 5 to 50 instances in which this relationship was empirically examined), involving from 50 to several thousand subjects. The meta-analytic statistics are derived from these hypothesis tests.

III. RESULTS

Time Pressure

The examination of the effects of stress as time pressure is restricted to operators performing signal detection and response integration tasks. Three performance indicators have been regularly examined in studies of the effects of time pressure: performance speed, performance accuracy, and heart

rate (a common physiological measure). The effects of time pressure on these distinct performance indicators were examined separately.

General Effects. A total of 58 hypothesis tests of the effects of time pressure on performance speed were analyzed (see Figure 2). There are significant (Z = 25.43, $p < .0001$) and strong (Fisher's Z = 0.542, r = .495, r^2 = .245, d = 1.138) effects for operators to perform more quickly under time pressure.[2]

The "fail-safe" number for significance presented in Figure 2 and in the following figures is informative. The fail-safe number addresses one objection to the meta-analytic procedure; that, for example, while the present results show highly significant results based on 58 hypothesis tests, there may be other "undiscovered" studies that show no effect, that if discovered would produce a different result. The fail-safe number in Figure 2 indicates that it would take 13,802 studies that show no effect to reduce the overall probability level to the p = .05 level of significance. In other words, it would take 13,802 studies showing no effect to overturn the results of this meta-analysis.

A total of 62 hypothesis tests of the effects of time pressure on performance accuracy were analyzed (see Figure 3). There are significant (Z = 21.65, $p < .0001$) and moderate (Fisher's Z = -0.432, r = -.407, r^2 = .165, d = 0.890) effects for operators to perform less accurately under time pressure.

A total of 27 hypothesis tests of the effects of time pressure on heart rate were analyzed (see Figure 4). The data indicate that the effects of time pressure on heart rate were small (Fisher's Z = -0.017, r = -.017, r^2 = .0003, d = -0.034) and nonsignificant (Z = 0.709, $p > .2$).

Effects of Moderators. One practically important moderator that can be reliably derived from studies of the effects of time pressure is the intensity or the magnitude of the time pressure under which operators must perform. The studies represented in this integration have operationalized time pressure in various ways (e.g., duration between stimulus presentations; percent of baseline self-paced time allotted for task performance). For example, a study may establish a baseline time for performance of a specific task at 20 seconds, and then introduce time pressure by setting the time limit at 10 seconds. Each hypothesis test comparing a condition of higher time pressure

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[2] Exact probability (p) values are available from the authors upon request.

General Combinations and Comparisons

58 Hypothesis Tests (Weighted by Unit 1)

Combination of Significance Levels
Z for combination = 25.4295
Associated one-tailed $p < .0001$
Fail-safe number ($p = .05$) = 13,802

Combination of Effect Sizes
Mean Fisher's Z = .5422
Mean r = .4946
Mean r^2 = .2447
Mean Cohen's d = 1.1383

Diffuse Comparison of Significance Levels
Chi-Square (57) = 642.5678
Associated one-tailed $p < .0001$

Diffuse Comparison of Effect Sizes
Chi-Square (57) = 51.3193
Associated one-tailed $p > .3$

Figure 2. Time Pressure and Speed of Performance.

General Combinations and Comparisons

62 Hypothesis Tests (Weighted by Unit 1)

Combination of Significance Levels
Z for combination = -21.6498
Associated one-tailed $p < .0001$
Fail-safe number ($p = .05$) = 10,677

Combination of Effect Sizes
Mean Fisher's Z = -.4316
Mean r = -.4063
Mean r^2 = .1653
Mean Cohen's d = -.8902

Diffuse Comparison of Significance Levels
Chi-Square (61) = 320.139
Associated one-tailed $p < .0001$

Diffuse Comparison of Effect Sizes
Chi-Square (61) = 39.8956
Associated one-tailed $p < .02$

Figure 3. Time Pressure and Accuracy of Performance.

General Combinations and Comparisons

27 Hypothesis Tests (Weighted by Unit 1)

Combination of Significance Levels
Z for combination = .7088
Associated one-tailed $p > .2$
Fail-safe number ($p = .05$) = -21

Combination of Effect Sizes
Mean Fisher's $Z = -.0168$
Mean $r = -.0168$
Mean $r^2 = .0284$
Mean Cohen's $d = -.0337$

Diffuse Comparison of Significance Levels
Chi-Square (26) = 107.8131
Associated one-tailed $p < .0001$

Diffuse Comparison of Effect Sizes
Chi-Square (26) = 95.8266
Associated one-tailed $p < .0001$

Figure 4. Time Pressure and Heart Rate.

with lower time pressure can be represented by a gauge of the relative difference in time pressure between those two conditions. We may define this index of magnitude of time pressure as:

time pressure = longer time period/(longer period + shorter period).

For example, if one study examines the effects of a 15-second time period on performance versus a 10-second time period, the index is calculated as: time pressure = 15/(15 + 10), or .6. If a second test examines the effects of a 15-second period versus a 5-second period, the index is calculated as: time pressure = 15/(15 + 5), or .75. Therefore, the larger the time pressure index, the greater or more extreme the manipulation of time pressure.

For performance speed, more intense manipulations of time pressure produced even greater enhancements of performance speed ($r = .482$, $Z = 1.880$, $p < .05$) (see Figure 5).

For performance accuracy, more intense manipulations produced even greater impairments of performance accuracy ($r = -.494$, $Z = 1.381$, $p < .05$) (see Figure 6).

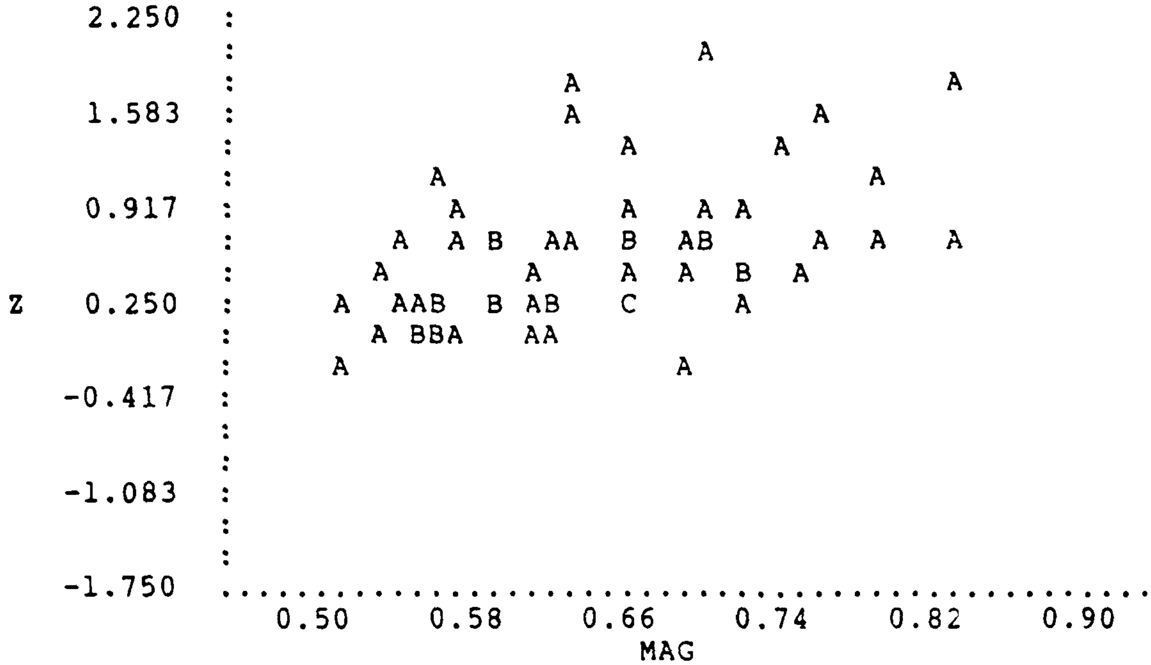


Figure 5. Scatterplot of Z for Effect Size and Magnitude: Speed of Performance

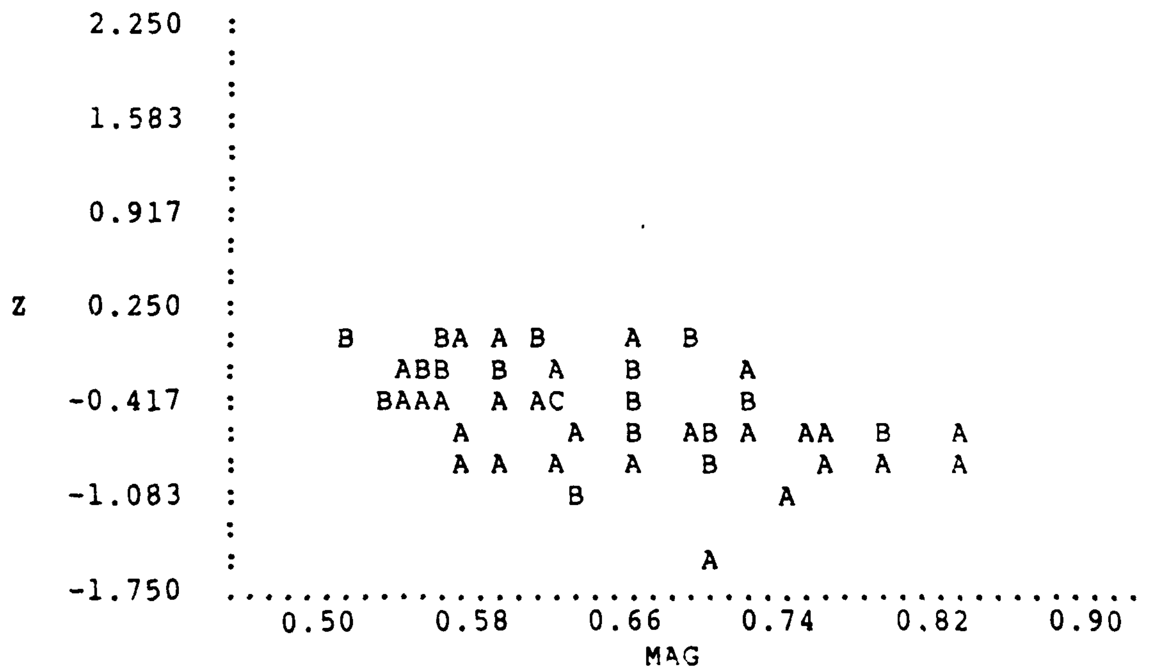


Figure 6. Scatterplot of Z for Effect Size and Magnitude: Accuracy of Performance

There was no variation in the effects of time pressure on heart rate as a function of the intensity of the time pressure manipulation (*r* = .028, *Z* = 0.226, *p* > .4) (see Figure 7).

```
     2.250 :
           :
           :
     1.583 :
           :
           :
     0.917 :
           :
           :                       AA
Z    0.250 :       A A B A  A   BA  A       A
           :     A    A  A   A  A      A     A
           :          A         A     A
    -0.417 :           A
           :                A
           :
    -1.083 :
           :             A
           :
    -1.750 ................................................
              0.50    0.58    0.66    0.74    0.82    0.90
                                MAG
```

Figure 7. Scatterplot of *Z* for Effect Size and Magnitude: Heart Rate

Implications. First, we know that as a stress manipulation, time pressure has significant and strong effects on speed and quality of performance. We will not know until other stress variables are examined how these effects compare in magnitude to those for other variables. At that point in Phase II of this research, we will be able to examine the magnitude of effect of time pressure on performance versus stressor A, B, C, etc., and then map out clear recommendations for manipulating stress via any number of critical variables. These data as they accumulate will provide information as to what variables are most critical in terms of manipulating the stress environment.

Second, we know that the effects of time pressure on speed and accuracy are straight, linear functions. At least within the considerable range represented by these studies, there is no apparent asymptote of the metric of time pressure, beyond which further increases have no effect. This information is important in terms of providing specifications to the training system designer; knowing that the effects of time pressure are linear

provides critical information concerning how this variable can be effectively manipulated.

Moreover, these linear effects of time pressure on speed and on accuracy were quite different. Although time pressure influenced both speed and accuracy, the effects on speed were more dramatic than the effects on accuracy. Thus, under a given increase in time pressure, operator speed will increase at a greater rate than operator accuracy will decrease. This may have implications for the performance and training of different tasks that require differing degrees of speed and accuracy. For example, consider a specific task in which effective performance has been estimated to be primarily determined by speed (75% speed) and less determined by accuracy (25%), such as replacing a particular equipment component. Further analysis of these data should identify the exact percentage of time pressure that maximizes performance speed without degrading performance accuracy to the point that it significantly impacts the task.

Third, we know that time pressure has no significant effects on one physiological indicator of stress, heart rate. This tells us, for example, that if we are manipulating time pressure in a maintenance combat simulation, it would be wise not to use a cardiovascular type of physiological measure such as heart rate as an index of stress. This may seem a relatively minor point, but is an example of the type of specific, applied information that will provide guidelines for manipulating the stress environment.

Finally, we can begin to provide some specific answers to the question of how to effectively manipulate time pressure as a stressor. The correlation coefficient ($\underline{r}$) is a useful index of magnitude of effect. In psychological research, levels of $\underline{r}$ are frequently characterized as small (.2 to .3), medium (.3 to .5), or large (.5 or greater), following Cohen's (1977) guidelines for effect size. In our analysis, we use the Fisher's $\underline{Z}$ transformation of $\underline{r}$ because $\underline{r}$ becomes non-linear at certain values, and Fisher's $\underline{Z}$ overcomes this problem. The only point of interest here is that for our immediate concerns, Fisher's $\underline{Z}$ approximates the correlation coefficient $\underline{r}$; so, an $\underline{r}$ of .2 equals a $\underline{Z}$ of .22; an $\underline{r}$ of .3 equals a $\underline{Z}$ of .31; and an $\underline{r}$ of .5 equals a $\underline{Z}$ of .549. Given this, we can look at Tables 1 and 2 to obtain a guideline for manipulating time pressure.

Column 1 of Table 1 represents the time pressure index (MAG, or magnitude) derived earlier. This index is calculated, as before, as:

MAG = longer time period/(longer period + shorter period).

Table 1. Manipulation of Time Pressure to Attain Small, Medium, and Large Levels of Effect: Performance Accuracy

Magnitude	Z	Minutes	Seconds
.54	-.209	1.70	102.0
.593	-.313	1.37	82.2
.71	-.543	.81	48.6

Table 2. Manipulation of Time Pressure to Attain Small, Medium, and Large Levels of Effect: Performance Speed

Magnitude	Z	Minutes	Seconds
.535	.209	1.70	102.0
.570	.310	1.51	90.6
.653	.549	1.06	63.6

Thus if a task with a baseline performance period of 2 minutes is performed by an individual who is given 2 minutes to perform the task, the MAG is: 2 minutes/(2 minutes + 2 minutes), or .50. Therefore, a MAG of .50 is equivalent to no time pressure. If the task performer is given 1 1/2 minutes to perform this same task, the MAG is: 2 minutes/(1 1/2 minutes + 1 1/2 minutes), or .67.

Column 1 presents the time pressure required to produce a Fisher's Z of approximately .2 (a small effect), .3 (a medium effect), and .5 (a large effect). As Table 1 indicates, a time pressure index or MAG of .54 is required to produce a small effect on performance accuracy; in this case, a 2-minute task would have to be performed in 1.70 minutes (column 3) or 102 seconds (column 4). Therefore, to produce a large or strong effect on performance accuracy using time pressure as a stressor requires a time pressure index (MAG) of .71. In this case, a 2-minute baseline task would have to be performed in .81 minute or 48.6 seconds. The minutes and seconds provided in Table 1 are given for a 2-minute task; however, exact numbers can be derived for a task of any length.

Table 2 provides similar information concerning how to effectively manipulate time pressure to produce a desired effect on performance speed. To produce a large or strong effect on performance speed using time pressure as a stressor requires a time pressure index (MAG) of .65. In this case, a 2-minute baseline task would have to be performed in 1.06 minutes or 63.6 seconds.

This type of analysis provides theoretically sound as well as practical guidelines on how to manipulate and measure stress to get accurate and consistent results.

Group Pressure

One factor that is likely to affect a maintenance technician in the combat environment is working in the presence of numerous others. The environment of a specialist working in a shop or in a classroom cubicle is quite different from the environment of a specialist working on a busy flightline. The present examination of the effects of stress as group pressure or group size is restricted to operators performing group problem-solving or brainstorming tasks either in a group or alone. Two performance indicators have regularly been examined in studies of the effects of group size: quantity of performance (analogous to speed) and quality of performance (analogous to accuracy). The effects of group size on these distinct performance indicators will be examined separately.

General effects. A total of 34 hypothesis tests of the effects of group size on quantity of performance were analyzed (see Figure 8). There were significant ($Z = 15.324$, $p < .0001$) and strong (Fisher's $Z = 0.650$, $r = .572$, $r^2 = .327$, $d = 1.395$) effects for groups to produce less output than the same number of individuals.

A total of 9 hypothesis tests of the effects of group size on quality of performance were analyzed (see Figure 9). There were significant ($Z = 10.592$, $p < .0001$) and strong (Fisher's $Z = 0.630$, $r = .558$, $r^2 = .311$, $d = 1.344$) effects for groups to produce lower quality performances than the same number of individuals.

Effects of Moderators. The specific effects of group size are presented in Figures 10 and 11. For quantity ($r = .606$, $Z = 19.130$, $p = < .0001$) and for quality ($r = .715$, $Z = 9.528$, $p = < .0001$), as the size of the group increased, the tendency for individuals to outperform groups increased dramatically.

Implications. These results document a very strong and significant phenomenon, that groups/teams/crews often exhibit performance decrements due to process loss, or the mere presence of other group members. This is likely to stem from environmental distractions, attention deficits, or any number of other factors. The present data indicate that the presence of others produces a strong effect on performance speed and accuracy. Group pressure is likely to be a very effective and easily accomplished stress manipulation, and should be considered as a component of a realistic stress simulation.

A good deal of maintenance training takes place in the shop or classroom with one technician working on one piece of equipment. Yet the combat environment is likely to be one in which other personnel predominate. Because of the dramatic effects of group pressure on performance, summarized for the first time in the above data, it is critical that maintenance personnel be prepared to operate in this environment. It would be well-advised to develop simulations that provide the capability to manipulate this variable for those tasks which will in fact be performed as part of a group, team, or crew, or simply performed in the presence of others in the combat battlefield.

Table 3 provides some specific information as to how manipulating group size affects performance. Based on the above data, and using the guidelines for effect size discussed earlier, working in a group of two seems to present enough of a distraction to produce a small effect on performance ($Z = .17$); a group of three produces a medium to large effect ($Z = .456$), and a group of four produces a very strong effect ($Z =$

General Combinations and Comparisons

34 Hypothesis Tests (Weighted by Sample Size)

Combination of Significance Levels
Z for combination = 15.3237
Associated one-tailed $p < .0001$
Fail-safe number ($p = .05$) = 2,827

Combination of Effect Sizes
Mean Fisher's $Z = .6505$
Mean $r = .572$
Mean $r^2 = .3272$
Mean Cohen's $d = 1.3946$

Diffuse Comparison of Significance Levels
Chi-Square (33) = 218.7737
Associated one-tailed $p < .0001$

Diffuse Comparison of Effect Sizes
Chi-Square (33) = 1111.21
Associated one-tailed $p < .0001$

Figure 8. Group Pressure and Quantity of Performance.

General Combinations and Comparisons

9 Hypothesis Tests (Weighted by Sample Size)

Combination of Significance Levels
Z for combination = 10.592
Associated one-tailed $p < .0001$
Fail-safe number ($p = .05$) = 252

Combination of Effect Sizes
Mean Fisher's $Z = .6295$
Mean $r = .5577$
Mean $r^2 = .3110$
Mean Cohen's $d = 1.3439$

Diffuse Comparison of Significance Levels
Chi-Square (8) = 103.5517
Associated one-tailed $p < .0001$

Diffuse Comparison of Effect Sizes
Chi-Square (8) = 170.9913
Associated one-tailed $p < .0001$

Figure 9. Group Pressure and Quality of Performance.

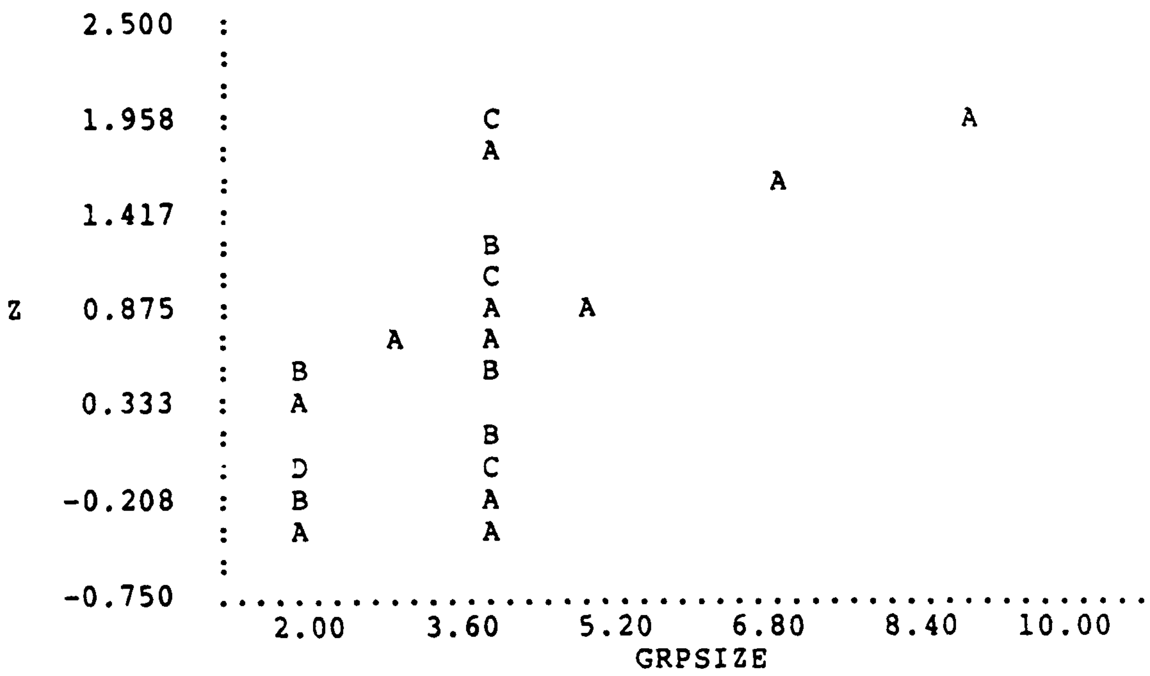


Figure 10. Scatterplot of Z for Effect Size and Group Size: Quantity of Performance

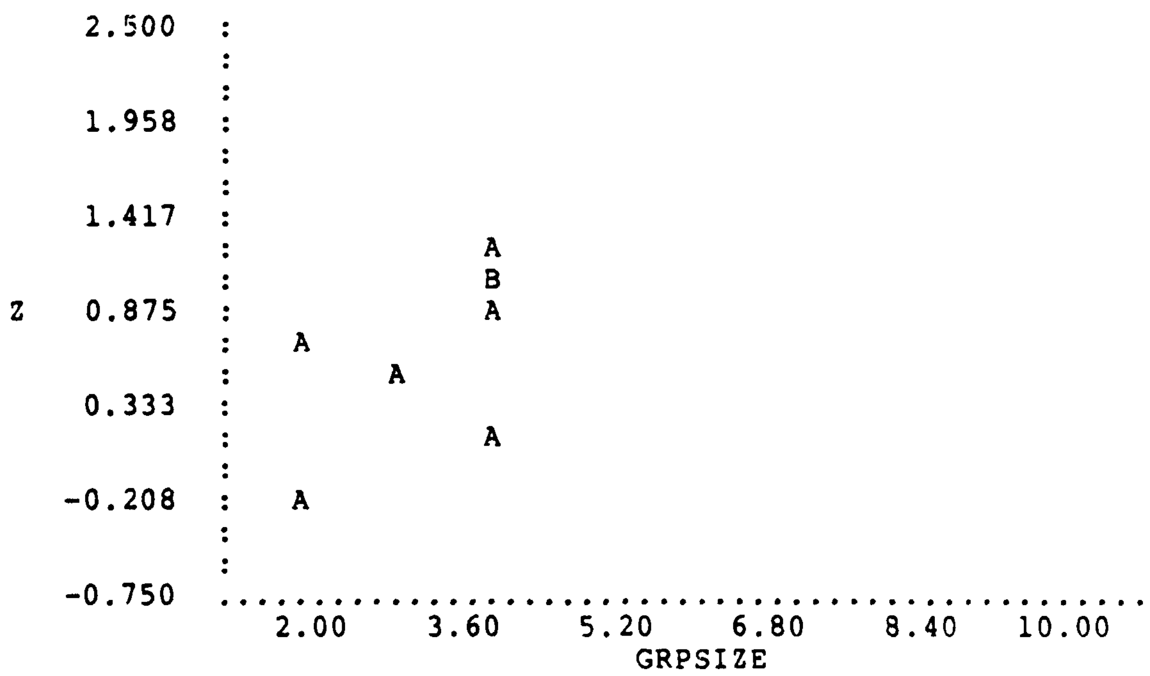


Figure 11. Scatterplot of Z for Effect Size and Group Size: Quality of Performance

Table 3. Manipulation of Group Size to Attain Small, Medium, and Large Levels of Effect

Group Size	Z
2	.170
3	.456
4	.742

.742). Therefore, designing a simulation that includes the pressure of working among and with others requires that at least three others be present in the immediate environment to produce a strong stress effect.

Noise

The present examination of the effects of noise-induced stress is restricted to operators performing signal detection and response integration tasks. Two performance indicators have regularly been examined in studies of the effects of noise: performance accuracy, and self-reports of stress, annoyance, or tension. The effects of noise on these distinct performance indicators will be examined separately.

General Effects. A total of 14 hypothesis tests of the effects of noise on performance accuracy were analyzed (see Figure 12). Significant (Z = 5.54, $p < .0001$) and weak to moderate (Fisher's Z = -0.241, r = -.237, r^2 = .056, d = -0.487) effects for noise to produce performance decrements were observed.

A total of 11 hypothesis tests of the effects of noise on self-reports of stress were analyzed (see Figure 13). Significant (Z = 13.98, $p < .0001$) and strong (Fisher's Z = -0.692, r = -.599, r^2 = .359, d = -1.496) effects for noise to produce reports of stress were observed.

Effects of Moderators. Additional analyses revealed several practically important moderators of the effects of noise on performance. One such moderator is the mode of delivery. The impairment in performance accuracy when noise was presented through earphones (Fisher's Z = -0.129) was significantly weaker (Z = 3.848, $p < .0001$) than the impairment when noise was

General Combinations and Comparisons

14 Hypothesis Tests (Weighted by Sample Size)

Combination of Significance Levels
Z for combination = -5.5384
Associated one-tailed $p < .0001$
Fail-safe number ($p = .05$) = 352

Combination of Effect Sizes
Mean Fisher's Z = -.2413
Mean r = -.2368
Mean r^2 = .0561
Mean Cohen's d = -.4874

Diffuse Comparison of Significance Levels
Chi-Square (13) = 62.9022
Associated one-tailed $p < .0001$

Diffuse Comparison of Effect Sizes
Chi-Square (13) = 35.0781
Associated one-tailed $p < .001$

Figure 12. Noise and Performance Accuracy.

General Combinations and Comparisons

11 Hypothesis Tests (Weighted by Sample Size)

Combination of Significance Levels
Z for combination = -13.9796
Associated one-tailed $p < .0001$
Fail-safe number ($p = .05$) = 845

Combination of Effect Sizes
Mean Fisher's Z = -.6917
Mean r = -.5991
Mean r^2 = .3589
Mean Cohen's d = -1.4964

Diffuse Comparison of Significance Levels
Chi-Square (10) = 41.9839
Associated one-tailed $p < .0001$

Diffuse Comparison of Effect Sizes
Chi-Square (10) = 87.6061
Associated one-tailed $p < .0001$

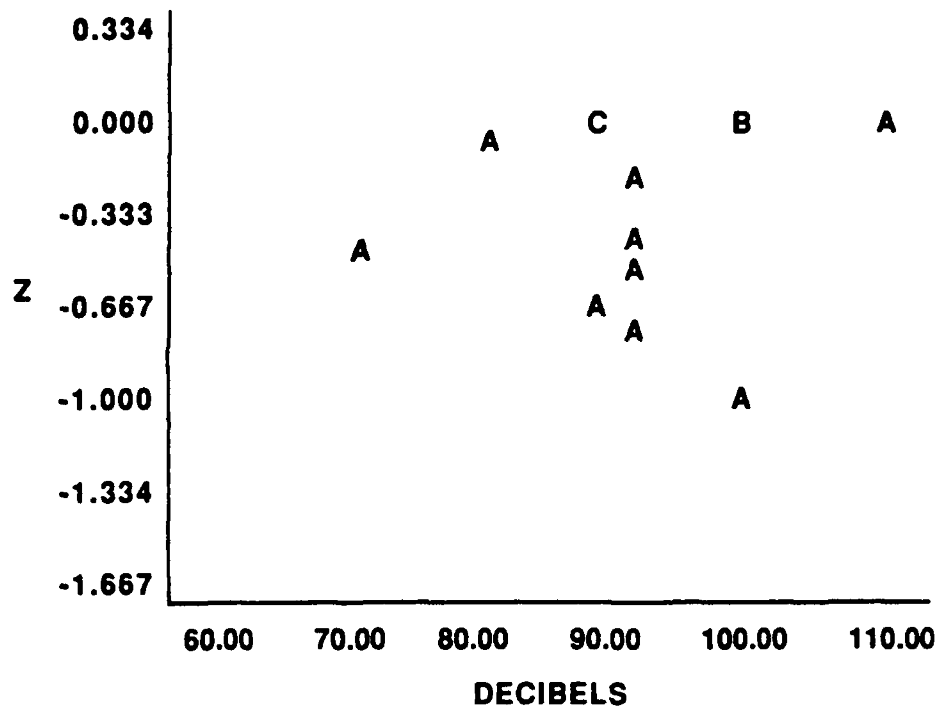
Figure 13. Noise and Self-Reported Stress.

presented through free-standing speakers (Fisher's $\underline{Z} = -0.393$). In other words, noise produces a stronger effect on performance accuracy when delivered through speakers. However, the self-report of stress when noise was presented through earphones (Fisher's $\underline{Z} = -0.814$) was somewhat stronger than the self-report of stress when noise was presented through free-standing speakers (Fisher's $\underline{Z} = -0.470$), although this difference was not statistically significant ($\underline{Z} = 0.810$, $\underline{p} > .2$). In other words, noise tended to produce a stronger effect on self-report of stress when delivered through earphones.

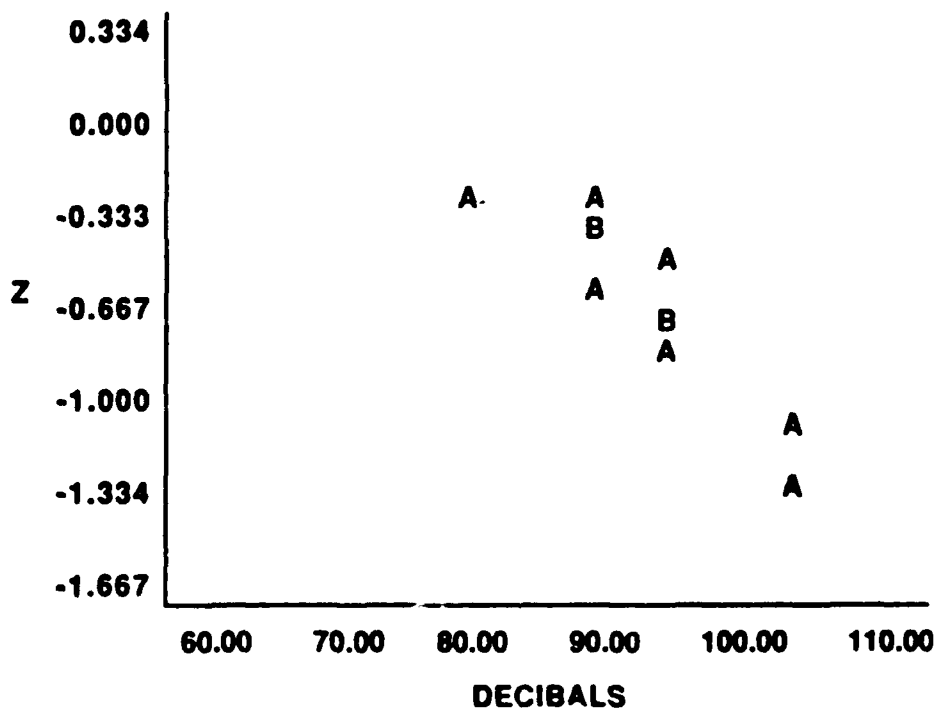
A second moderator is noise level. The specific effects of noise level are presented in Figures 14 and 15. The impairment in performance accuracy overall did not appear to be related to the decibel level of the noise ($\underline{r} = .012$, $\underline{Z} = 0.084$, $\underline{p} > .4$) (see Figure 14). However, this apparent lack of effect of noise level overall masked opposing effects of noise level that occurred as a function of the mode of delivery. When noise was presented through earphones, louder noises led to an insignificant enhancement of performance ($\underline{r} = .362$, $\underline{Z} = 1.316$, $\underline{p} > .09$). However, when noise was presented through free-standing speakers, louder noises led to significant impairments of performance ($\underline{r} = -.488$, $\underline{Z} = 1.919$, $\underline{p} < .05$).

The negative self-reports of stress increased as a function of decibel level ($\underline{r} = -.912$, $\underline{Z} = 8.912$, $\underline{p} < .0001$) (see Figure 15). This effect occurred both for noise presented through earphones ($\underline{r} = -.976$, $\underline{Z} = 7.978$, $\underline{p} < .0001$), and for noise presented through free-standing speakers ($\underline{r} = -.877$, $\underline{Z} = 2.544$, $\underline{p} < .01$).

A third moderator is continuous noise versus noise bursts. The greater the percent of the task performance period with noise (the more continuous the noise), the worse the performance accuracy ($\underline{r} = -.599$, $\underline{Z} = 3.703$, $\underline{p} < .001$). However, the more continuous the noise, the less negative the self-reports of stress ($\underline{r} = .265$, $\underline{Z} = 1.769$, $\underline{p} < .05$). In other words, there are stronger effects of noise on performance accuracy when the noise is continuous. There are stronger effects of noise on self-reports of stress when the noise is discontinuous or in bursts. This last discrepancy between self-report and performance is particularly informative. It lends support to various conceptualizations of stress, adaptation, and information processing: As noise becomes more and more frequent, and thereby more predictable, the operator may find it easier to cope with the noise by effectively blocking out environmental input (at least in an emotional sense as evidenced by self-reported stress). However, this effective coping strategy leads to further decrements in performance, as important task-relevant pieces of information are ignored or



<u>Figure 14.</u> Scatterplot of <u>Z</u> for Effect Size and Decibels: Performance Accuracy .



<u>Figure 15.</u> Scatterplot of <u>Z</u> for Effect Size and Decibels: Self-Reported Stress

distorted due to the direction of attention away from the environmental stimulation.

Implications. Several important patterns emerged in this analysis that were not part of our prior body of knowledge on noise effects. This analysis serves as a good example of the information that can be integrated and summarized through this meta-analytic procedure.

To interpret these results, consider the following framework. Researchers in the stress field have identified three critical components of stress training: (a) indoctrination, (b) skills training, and (c) confidence drill. The purpose of the indoctrination component of stress training is to provide the individual with information about the stress environment. Knowledge provided in this manner is relatively straightforward, and may be delivered via classroom sessions, handbooks, and the like. The purpose of skills training is to provide the individual with exposure to the stress environment, have the individual experience skill degradation in terms of decreased performance accuracy or speed, and then develop work-around procedures or allow adaptation to the environment so that performance returns to an acceptable level. The purpose of the confidence drill is to provide the individual with exposure to the stress environment, to allow the individual to operate effectively in that stress environment, and to develop positive expectations regarding his or her ability to perform under stress conditions.

Given this framework, the noise analysis suggests that we may want to design a very different stress simulation for skills training versus a confidence drill (see Table 4). If our primary purpose of training is to allow skills development in a stress environment, we would be principally concerned with column 1 of Table 4; i.e., those factors that affect performance accuracy. If our primary purpose of training is building confidence, then we are principally concerned with column 2 of Table 4; i.e., those factors that most affect self-reports or cognition.

Noise produced stronger effects on performance accuracy when delivered through free-standing speakers and when the noise was continuous, and these effects increased as a function of decibel level. Noise produced stronger effects on self-reports of stress when delivered through earphones and when the noise was provided in discontinuous bursts, and these effects also increased as a function of decibel level.

Table 5 provides specific information concerning how to effectively manipulate noise. Table 5 refers to the effect of decibel level on self-reported stress. Decibel (dB) levels

Table 4. Noise Manipulations for Skills Training Versus a Confidence-Building Drill

	PERFORMANCE	SELF-REPORT
GENERAL EFFECTS	Highly significant, weak to moderate performance impairment due to noise	Highly significant, strong aversive self-report response to noise
MODE OF DELIVERY (Earphones vs. Speaker)	Stronger effects with external speakers	Stronger effects with earphones
DECIBELS	– Increased performance impairment as a function of decibels for continuous noise – Decreased performance impairment as a function of decibels for noise bursts	Stronger aversive reactions as a function of decibels
CONTINUOUS NOISE VS. BURSTS	Stronger performance impairment with continuous noise	Stronger aversive reactions with noise bursts
NUMBER OF BURSTS	No effect	The greater the number of bursts, the less the aversive reaction

Table 5. Manipulation of Decibel Level to Attain Small, Medium, and Large Levels of Effect

Decibels	Z
80	.016
85	-.223
87	-.319
92	-.559

typically may range from a whisper (about 40 dB) to normal speech (about 50 - 65 dB) to a shout (about 80 dB) to a very noisy work environment (around 90 dB). The data in Table 5 indicate (according to guidelines for effect size used earlier) that a decibel level of 80 produces little discernible effect on stress; a decibel level of 85 produces a small effect; a decibel level of 87 produces a medium effect; and a decibel level of 92 produces a large or strong effect.

Again, these data provide specific, practical guidelines for effectively manipulating noise to simulate the stress environment.

IV. CONCLUSIONS

The Phase I research described in this paper has achieved two primary goals. First, the research has demonstrated the feasibility of the technical approach. We have accessed the relevant literature on time pressure, group pressure, and noise; analyzed and integrated the results according to a well-accepted meta-analytic procedure; and provided data that directly address the technical problem of how to effectively simulate the stress environment.

The second goal achieved in Phase I was that the results of this project have provided practical information on time pressure, group pressure, and noise that simply was not available prior to this analysis. The Phase I research was conducted primarily to establish the feasibility of this approach; i.e., to test the methodology. The results of the time pressure, group pressure, and noise analyses must be

considered as preliminary, in that the complete analysis of these and other variables is to be carried out in Phase II. Nevertheless, we know a great deal more about these variables than was known prior to this research. The bottom line is that we can use this emerging information on stress effects to enhance maintenance performance in the combat environment.

The successful accomplishment of the Phase I research provides a foundation for the Phase II effort. The work to be conducted in Phase II will identify, for each of the major stressors identified in the combat stress literature, the magnitude and direction of effects on performance speed, performance accuracy, physiological effects, and psychological effects; what characteristics, such as type of training or type of task, moderate these relationships; and precisely how to manipulate each stressor to provide an effective simulation of the stress environment.

The objective of this research is to develop a set of standard procedures, or functional specifications, for simulating the combat stress environment that can be used in laboratory and field test, training, and equipment design applications. The resulting document will specify, in practical terms, the expected effect of each identified stressor on task performance, how to manipulate that stressor, and what characteristics have been identified that moderate the effects of that stressor on performance. The payoff of this effort will accrue in several areas.

This document will serve as a handbook for the researcher that will allow him or her to do several things. First and foremost, the results of this project will be directly applicable to enhancing human performance in stressful environments. One strategy is to develop training and simulation procedures to support the maintenance performer by providing pre-exposure to an effective simulated combat maintenance environment. This project will allow effective training procedures and training overlays to be developed according to a standard, reliable, and consistent baseline. The mitigation of the negative effects of stress through training is critical to military mission performance. One payoff of this project, therefore, is to develop an effective procedure to simulate stress conditions for training purposes.

Second, the document can be used as a sourcebook to develop functional specifications for training system procurement. Consider the researcher whose goal is to design a large-scale, controlled environment for simulating the combat maintenance environment. The researcher can provide the engineer with precise specifications for physical parameters; for example, the facility may have to be this large to allow this type of

exercise, it may require two operator stations and one instructor station, and so forth. However, when providing the engineer with information on the parameters required to simulate the psychological environment of combat, the researcher is usually left to his or her own wits. The comprehensive functional specification guidelines that will result from the Phase II research will provide the researcher with a tool to answer these questions. With the information provided by this research, researchers will be able to specify, for example, that they want the capability to manipulate noise from a range of 80dB to 95dB, providing both continuous noise and noise bursts; they want the capability to measure specific types of performance and physiological indicators because such measures have been shown to be reliable measures of noise; they want to vary the type of task performed from simple to complex or from rote to non-rote because type of task has been shown to be a critical moderator of noise effects; etc. Furthermore, they will be able to provide this information for <u>every</u> stressor considered critical.

Therefore, a second outcome of this project will be to provide a sound experimental setting for the examination of stress effects, or for the examination of stress interventions or approaches to reduce stress. Rather than relying on weak approximations of the stress environment used in most academic research, this project will allow the development of a "prototype stress setting" for research purposes. Subsequent research may use variations of this setting to test innovative training approaches and perform other studies.

Third, this project will provide what is unquestionably the most comprehensive database available on stress and human performance. It is important to remember that if there are 100 studies available in a particular domain, such as the effects of threat on psychological reactions, we will have conducted the meta-analytic integration on that <u>entire</u> population of studies. The resulting data will represent a completely representative sampling (i.e., the entire population) of a subject area, and are data in which one can have a large degree of confidence. Furthermore, these data are relevant to any military task that requires performance under stress or emergency conditions.

Finally, these data will identify profitable avenues for research. One advantage of a meta-analysis is that it may point out relationships among data that might not have been apparent without this precise inspection. For example, we may find, when we have the opportunity to examine 40 studies on threat and psychological reactions, that leadership plays a critical role in moderating the severity of stress effects. This, in turn, would provide direction for high-payoff research opportunities: Based on this example, an analysis of the leadership role may be indicated. This process will enable us to make more intelligent

decisions as to what research should be pursued to increase the performance of combat maintenance personnel.

The end result of this research will be the enhanced performance of maintenance personnel who, when the situation arises, must perform critical mission tasks effectively in a high stress combat environment.

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APPENDIX: GLOSSARY

Abstracting Services: A strategy for locating studies that are associated with key words or phrases.

Ancestry Approach: A strategy for locating earlier studies from the bibliography and reference sections of already-located studies.

Blocking: The technique of disaggregating the k-included hypothesis tests into subgroups defined by levels of some categorical predictor, and then performing the basic combination and comparison procedures within each block, or level, of the categorical predictor.

Combination of Effect Sizes: The mean effect size for the k-included hypothesis tests.

Combination of Significance Levels: The probability that the significance levels of the k-included hypothesis tests might have been obtained if the null hypothesis were true.

d(Cohen's d): A number representing the effect size in terms of standard deviation units. That is, the difference between the means of two groups divided by some index of the standard deviation of the measurements involved.

Database: The entire constellation of statistical and predictor information for each hypothesis test included in the meta-analysis.

Descendency Approach: A strategy for locating studies that obtains subsequent studies that have cited earlier, already-located studies.

Diffuse Comparisons of Effect Sizes: A technique that indicates the extent to which there is a significant amount of heterogeneity in significance levels among the k-included hypothesis tests.

Diffuse Comparisons of Significance Levels: A technique that indicates the extent to which there is a significant amount of heterogeneity in significance levels among the k-included hypothesis tests.

Direction of Effect: The directional pattern of relation between two variables (i.e., whether Y increases or decreases as a function of X). Direction of Effect is often coded as being in the expected direction ("+") or in the unexpected direction ("-").

Effect size: The strength or magnitude of an effect.

Fail-safe number: An estimate of the number of unretrieved studies averaging null results, or no effect, that would be needed to bring the combined results of a body of research to some specified minimal level.

Focused Comparison of Effect Sizes: A technique indicating the extent to which the effect sizes of the k-included hypothesis tests are significantly predictable in some systematic, specifiable manner.

Focused Comparison of Significance Levels: A technique indicating the extent to which the significance levels of the k-included hypothesis tests are significantly predictable in some systematic, specifiable manner.

Hypothesis Test: A primary-level statistical test of some well-defined, directional statement of the effect of one variable on another.

Invisible College: The informal network of scientists working on the same problem: a strategy for locating studies that obtains studies from individual researchers who are active in the field.

k: The number of studies in the database.

Meta-Analysis: The statistical integration of the results of independent studies.

p (Probability Value): A number, ranging from 0.0 to 1.0, which represents how improbable a statistic would be if the hypothesis being tested were true.

Primary Analysis: The original statistical analysis of data by the researcher who collected the data.

r (product-moment correlation coefficient): A number representing effect size that ranges from -1.00 (perfect inverse relation) to +1.00 (perfect direct relation).

r^2 (coefficient of determination): The percentage of variability accounted for by a particular variable.

Scatterplot: A graphic display of a correlation. Meta-analytic scatterplots usually present effect size on the vertical axis and a predictor on the horizontal axis.

Secondary analysis: The analysis of data by someone other than the researcher who collected the data, for purposes or with analytic strategies other than those of the original researcher.

Significance level: The degree of improbability which is deemed necessary to cast sufficient doubt upon the truth of a hypothesis to warrant its rejection.

Z (Standard Normal Deviate): A standardized metric that has a mean of zero and a variance of one.

Z_{FISHER} *(Fisher's Z transformation of r):* A standardized metric representing effect size that makes the sampling distribution of r approximately Gaussian.